TITLE OF THE INVENTION

APPARATUS AND METHOD FOR OBTAINING SHAPE DATA OF

ANALYTIC SURFACE APPROXIMATE EXPRESSION

CROSS-REFERENCE TO RELATED APPLICATIONS

5    This application is based upon and claims the

benefit of priority from the prior Japanese Patent

Application No. 2000-099874, filed March 31, 2000,

the entire contents of which are incorporated herein

by reference.

10      BACKGROUND OF THE INVENTION

    The present invention relates to an apparatus and

method for generating shape data of analytic surface

approximate expression by use of three-dimensional

shape data approximated by a combination of a plurality

15  of polygons.

    Nowadays, CAD (Computer Aided Design) systems,

model generation software systems, computer animation

software systems, and the like are used to efficiently

design products such as machines, architectures, and

20  the like.

    VRML (Virtual Reality Modeling Language), which is

a standard for exchanging and using three-dimensional

shape information of components via the Internet, has

been proposed, and is used in practice.  Expression of

25  shape data in VRML is an approximation of a three-

dimensional shape of an object using a set of a

plurality of polygons (polyhedron), and the shape data

is widely distributed.

In a given CAD system, kinematic pairs such as coincidence, coaxial, and the like are defined among features (partial shapes such as a cylindrical surface, plane, and the like) as partial shapes of machine components for the purpose of aiding a complicated machine product design using a computer, the positional relationship among components in an assembly is defined and managed, and various functions such as assembly modeling, mechanism simulation, and interference check are implemented. These functions are essential features of a CAD system, and are very effective in design aid.

However, like as the above CAD system cannot use shape data by polyhedron approximation like in VRML. Hence, compatibility and reusability of shape data such as VRML must be improved.

BRIEF SUMMARY OF THE INVENTION

The present invention has been made in considera- tion of the above situation, and has as its object to provide an apparatus and method for obtaining shape data of analytic surface approximate expression which can be used in a CAD system having various functions such as assembly modeling, mechanism simulation, interference check, and the like.

According to one aspect of the present invention, there is provided a method of generating

three-dimensional shape data in analytic surface
expression form by using polygonal shape data in which
at least a portion of a shape is approximated by
a combination of a plurality of polygons, the method
5  comprising: obtaining a set of polygons from the
polygonal shape data, each of the polygons satisfying a
predetermined selection criterion; fitting an analytic
surface in place of the obtained set of polygons; and
repeating the step of fitting by obtaining another set
10  of polygons until a predetermined termination condition
is satisfied.

According to another aspect of the present
invention, there is provided a method for obtaining
three-dimensional shape data in analytic surface
15  expression form by using polygonal shape data in
which at least a portion of a shape is approximated by
a combination of a plurality of polygons, the method
comprising: selecting at least one or more polygons
from the polygonal shape data in accordance with
20  a predetermined selection criterion; and calculating
an analytic surface to be assigned for the one or more
polygons.

According to another aspect of the present
invention, there is provided an apparatus for
25  generating three-dimensional shape data of analytic
surface expression, the apparatus comprising: a storage
configure to store polygonal shape data in which

at least a portion of a shape is approximated by
a combination of a plurality of polygons; a shape data
I/O interface configure to read the polygonal data from
the storage; and an analytic surface fitting device
5      coupled to the shape data I/O interface, including:
a generation device configured to generate a set
of polygons from the polygonal shape data, each of
the polygons satisfying a predetermined selection
criterion; an analytic surface computation device
10     configured to compute a shape parameter of analytic
surface, the analytic surface being fitted in place of
the obtained set of polygons; and a fitting process
controlling device configured to control a fitting
process by activating the generation device and
15     analytic surface computation device based on
a predetermined termination condition.

According to still another aspect of the present
invention, there is provided an apparatus for
generating three-dimensional shape data of analytic
20     surface expression, the apparatus comprising: a storage
configured to store polygonal shape data in which
at least a portion of a shape is approximated by a
combination of a plurality of polygons; a shape data
I/O interface configure to read the polygonal data from
25     the storage; and analytic surface fitting means coupled
to the shape data I/O interface, including: generation
means for generating a set of polygons from the

polygonal shape data, each of the polygons satisfying a predetermined selection criterion; computation means for computing a shape parameter of analytic surface, the analytic surface being fitted in place of the obtained set of polygons; and fitting process controlling means for controlling a fitting process by activating the generation means and computation means based on a predetermined termination condition.

According to still another aspect of the present invention, there is provided an apparatus for obtaining three-dimensional shape data in analytic surface expression form by using polygonal shape data in which at least a portion of a shape is approximated by a combination of a plurality of polygons, the apparatus comprising: means for selecting at least one or more polygons from the polygonal shape data in accordance with a predetermined selection criterion; and means for calculating an analytic surface to be assigned for the one or more polygons.

According to still another aspect of the present invention, there is provided an article of manufacture comprising a computer usable medium having computer readable program code means embodied for obtaining three-dimensional shape data in analytic surface expression form by using polygonal shape data in which at least a portion of a shape is approximated by a combination of a plurality of polygons, the computer

readable program code means comprising: computer

readable program code means for causing a computer to

select at least one or more polygons from the polygonal

shape data in accordance with a predetermined selection

5      criterion; and computer readable program code means for

causing a computer to calculate an analytic surface to

be assigned for the one or more polygons.

According to still another aspect of the present

invention, there is provided an interference check

10     method for checking the presence/absence of geometric

interference between three-dimensional shapes using

shape data in which at least a portion of a three-

dimensional shape is approximately expressed by a

combination of a plurality of polygons, the method

15     comprising: obtaining shape data of analytic surface

expression by fitting partial sets of the polygons

to analytic surfaces; selecting one of an accuracy-

oriented processing method and processing

speed-oriented processing method of the interference

20     check; selecting one of the shape data of polygon

approximate expression and the shape data of analytic

surface expression according to the selected processing

method; and executing the interference check using the

selected shape data.

25     According to still another aspect of the present

invention, there is provided an interference check

apparatus for checking the presence/absence of

geometric interference between three-dimensional shapes
using shape data in which at least a portion of a
three-dimensional shape is approximately expressed by
a combination of a plurality of polygons, comprising:
an analytic surface fit processing device configured
to obtain shape data of analytic surface expression
by fitting partial sets of the polygons to analytic
surfaces; a storage configured to store the shape data
of the three-dimensional shape approximately expressed
by polygons, and corresponding shape data of analytic
surface expression in association with each other;
a computation mode selecting device configured to
select one of an accuracy-oriented computation mode
and processing speed-oriented computation mode of the
interference check; a shape data selecting device
configured to select one of the shape data of polygon
approximate expression and the shape data of analytic
surface expression according to the computation mode
selected by the computation mode selecting device; and
an interference check device configured to execute
the interference check process using the shape data
selected by the shape data selecting device.

According to still another aspect of the present
invention, there is provided an article of manufacture
comprising a computer usable medium having computer
readable program code means embodied for checking the
presence/absence of geometric interference between

three-dimensional shapes using shape data in which
at least a portion of a three-dimensional shape is
approximately expressed by a combination of a plurality
of polygons, the computer readable program code means
5     comprising: computer readable program code means for
causing a computer to obtain shape data of analytic
surface expression by fitting partial sets of the
polygons to analytic surfaces; computer readable
program code means for causing a computer to select
10    one of an accuracy-oriented processing method and
processing speed-oriented processing method of the
interference check; computer readable program code
means for causing a computer to select one of the shape
data of polygon approximate expression and the shape
15    data of analytic surface expression according to the
selected processing method; and computer readable
program code means for causing a computer to execute
the interference check using the selected shape data.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

20         FIG. 1 shows a functional block diagram of
an apparatus according to the first embodiment of
the present invention;

         FIG. 2 is a schematic flow chart showing a process
of the apparatus of the first embodiment.

25         FIG. 3 shows an example of three-dimensional shape
data approximately expressed by combinations of
a plurality of polygons;

FIG. 4 shows an example of shape data of analytic surface expression generated based on shape data of polyhedron approximate expression shown in FIG. 3;

FIG. 5 shows an example of a three-dimensional object expressed by read polygon data (shape data);

FIG. 6 shows contents of groups as the execution result of a pre-process;

FIG. 7 shows reference polygons selected for respective groups;

FIG. 8 shows a set of polygons that satisfy neighbor criteria;

FIG. 9 shows determination of second reference polygons;

FIG. 10 shows neighboring polygons that satisfy criteria for the second reference polygons;

FIG. 11 shows determination of third reference polygons;

FIG. 12 shows neighboring polygons that satisfy a criterion for the third reference polygons;

FIG. 13 shows addition of new polygons that can be fitted;

FIG. 14 shows determination of fourth reference polygons;

FIG. 15 shows neighboring polygons that satisfy a criterion for the fourth reference polygons;

FIG. 16 shows polygons which are added and fitted;

FIG. 17 shows determination of fifth reference

polygons;

FIG. 18 shows neighboring polygons that satisfy a criterion for the fifth reference polygons;

FIG. 19 shows a result after fitting destinations have been changed;

FIG. 20 is a view for explaining categories and definitions of tori;

FIG. 21 shows shapes that have already been fitted in analytic surfaces as objects that are to undergo a mechanism simulation;

FIG. 22 shows the storage format of relation information associated with FIG. 21 in a storage means such as a memory or the like of a computer in the form of a graph;

FIG. 23 shows an example of the positional relationship among components, which is computed to satisfy all coincidence relationships defined among partial shapes, i.e., all constraint relationships among partial shapes;

FIG. 24 is a flow chart showing a series of steps from read of shape data that pertain to polyhedron approximate expression to the end of interference check according to an embodiment of the present invention;

FIG. 25 is a block diagram showing an example of the configuration of a program that implements a series of steps from read of shape data that pertain to polyhedron approximate expression to the end of

interference check on a computer;

FIG. 26 shows a case wherein an analytic surface is accurately fitted in a three-dimensional shape shown in FIG. 19 (without errors);

FIG. 27 is a view for explaining a case wherein analytic curve fitting produces errors for three-dimensional shape data which is different from that in FIG. 19;

FIG. 28 shows fitting errors of the analytic surface for the three-dimensional shape shown in FIG. 27;

FIG. 29A shows fitting (shaft-hole pair) between a shaft (cylindrical surface) and hole by analytic surface expression;

FIG. 29B shows fitting (shaft-hole pair) between a shaft (cylindrical surface) and hole by polyhedron expression;

FIG. 30 is a view for explaining redundant approximate expression of a three-dimensional shape;

FIG. 31A is a view for explaining another redundant approximate expression of a three-dimensional shape; and

FIG. 31B is a view for explaining still another redundant approximate expression of a three-dimensional shape.

## DETAILED DESCRIPTION OF THE INVENTION

(First Embodiment)

The first embodiment of the present invention will be described below.

FIG. 1 shows a functional block diagram of an apparatus according to the first embodiment of the present invention.  As shown in FIG 1, the apparatus comprises a shape data interface (I/F) 111, an analytic surface fitting module 130, a shape parameter computation module 132, a polygon set generating module 133, a fitting accuracy evaluation module 134, a candidate polygon selecting module 135, and a boundary of fitted surface processing module 136.

Shape data 200 inputted to the apparatus of this embodiment is three-dimensional data of objects by polyhedron approximation like in VRML.  The apparatus of this embodiment is coupled to a mechanism simulation system 137 and an interference check system 138.

FIG. 2 is a schematic flow chart showing a process of the apparatus of the first embodiment.  In this flow chart, a portion bounded by S11 indicates the input step, and a portion bounded by S12 indicates the analytic surface fitting step.  Steps S21 to S31 show detailed processing steps as an implementation example of input step S11 and analytic surface fitting step S12.  The results obtained by input step S11 and analytic surface fitting step S12 are used in

a mechanism simulation S32 and an interference check
process S33.

The processing contents in steps S21 to S31 in
FIG. 2 will be described in detail below.

In this processing, a fitting process control
module 131 shown in FIG 1 activates modules necessary
for executing processes constituting the fitting
process of analytic surface to the read polygon data.

In shape data read step S21, shape data which
is partially or entirely expressed by polyhedrons is
read from, e.g., a file 200 or the like.  Each of
polyhedrons will be referred to as a "polygon".  This
process is performed by a shape data read module 121.

FIG. 3 shows an example of shape data in which
the entire three-dimensional shape is approximately
expressed by a combination of a plurality of
polyhedrons.  This data corresponds to a three-
dimensional shape obtained by cropping an infinite
cylindrical surface by two surfaces.  Vertex data are
listed as combinations of ID numbers and coordinate
values, and triangles are described by ID number
sequences of vertices.  Such shape data of polyhedron
approximate expression has huge numbers of vertices and
polygons, and a larger data size than shape data of
analytic surface expression (to be described later).

In this specification, an analytic surface is
defined by a quadratic surface or a combination

thereof.

FIG. 4 shows an example of the shape data of
analytic surface expression generated based on the
shape data of polyhedron approximate expression shown
in FIG. 3. As for a cylindrical surface, the
coordinate value of one point on its axis and a
direction vector of the axis are output to express the
axis, and data of a radius is added thereto. As for a
plane, the coordinate value of one point on a plane and
a vector normal to that point are output. Since these
data can only express an infinite cylinder and infinite
plane, contour information is added. A right or left
attribute attached to contour indicates the right or
left side where the surface is present when viewed from
the direction of an arrow in FIG. 4 (counterclockwise
about the axis of the edge). An arc edge is expressed
by center, axis, and radius data, and endpoints having
an identical coordinate value indicate the entire
perimeter of an arc. The same applies to an ellipse,
which also has vector data of its long axis (major
axis).

FIG. 5 shows an example of a three-dimensional
object expressed by polygon data (shape data) read in
shape data read step S21. FIG. 6 shows the contents of
groups (polygon groups A and B) as the execution result
of pre-processing step S22.

In pre-processing step S22, it is checked if

neighboring polygons have a common ridgeline by determining if they have identical endpoints. If identical ridgelines are present between two polygons, it is determined that these two polygons neighbor via

5       a common ridgeline. All polygons are searched for such neighbor relationship, and the found relationships are stored as attribute information of polygons. Tracking the stored neighbor relationships of polygons, polygons that can reach each other are classified into one

10      group. In the preferred embodiment, polygons are classified into a plurality of groups in advance. If the following processes are performed in consideration of the grouping, the overall processing speed can be improved. This process is performed by a shape data

15      pre-processing module 122.

In step S23 of reference polygon selection for surface fitting, reference polygons are respectively selected from polygon groups A and B. In this embodiment, a polygon having the largest area is

20      selected from a group of polygons. FIG. 7 shows reference polygons respectively selected from groups A and B. This process of selection of reference polygon 1331 is performed by a polygon set generation module 133.

25      In step S24 of polygon set generation, a set of polygons which satisfy the following criteria is generated by tracking polygons in turn from a polygon

that neighbors each reference polygon selected in reference polygon selection step S23. That is, polygons which satisfy criteria: neighboring polygons make an angle which is equal to or smaller than a predetermined angle, and a polygon makes an angle which is equal to or smaller than a predetermined angle with the reference polygon selected in reference polygon selection step S23 are selected. Sets of polygons which satisfy neighbor criteria are hatched in FIG. 8. This process of grouping polygons that neighbor the reference polygon 1332 is performed by the polygon set generation module 133.

Note that the set of polygons may be generated not depending on the reference polygon but on another criteria of polygon selection.

In fitting step S25 of a plane, cylindrical surface, and torus, attempts are made to fit the polygon sets selected in the previous step in a plane, conic surface, and torus.

The torus has two definitions in accordance with the distance between the axis and sectional arcs, as shown in FIG. 20. In case of a definition 51 of the torus, that shape is called a "lemon portion of torus". In case of a definition 52 of the torus, that shape is called a "apple portion of torus". In fitting step S25, fitting is made for a plane, conic surface, lemon portion, and apple portion. Since a cylinder is

a special expression of a cone, and a sphere is that of a torus (an intermediate shape between apple and lemon portions is a sphere), a cylinder and sphere are extracted last (cylinder/sphere identification step S30).

These processes (i.e., plane fitting, cone fitting, and torus fitting ) are performed by the shape parameter computation module 132.

It should be noted that the processing of extraction of the cylinder 1321 and sphere 1322 are performed by the computation module 132.

In neighboring polygon fitting step S26, assuming that the cone or torus is a fitting surface, it is checked if a neighboring, nonfit polygon can be fitted in the cone or torus with a sufficiently small error. As a result, if the number of polygons to be fitted increases, the fitted curved surface is modified to attain fitting with high accuracy (YES in branch step S27). The evaluation of the error in this process is performed by the fitting accuracy evaluation module 134. The nonfit polygon is selected by the polygon set generation module 133.

The polygon which is fitted in the aforementioned process is moved from the initial polygon set to a new one, and is managed together with attribute information (central position, direction of axis, and the like) indicating the type and the shape of surface in which

that polygon is fitted. If polygons to be fitted still remain in the polygon set, the fitting process is repeated. Upon completing of fitting for all the polygon sets and polygons with the aforementioned processes ("YES" in branch process step S28), the flow advances to a fitting surface movement process S29.

The fitting surface reassignment process S29 is a process for further improving the fitting result. In the case where a neighboring polygon is fitted in a different surface from a surface of polygon of interest, a fitting error between the polygon of interest and the neighboring polygon's surface is computed and is compared with current error. If the fitting error decreases, the polygon of interest is reassigned to the neighboring polygon's surface. By sequentially executing such process for all the polygons, the initial fitting result can be further improved. The module 135 selects such candidate of polygons with reference to the result of the evaluated fitting accuracy by the fitting accuracy evaluation module 134.

A termination condition of the above fitting process is not limited only such a condition in which all of the polygons are fitted to any one of analytic surfaces, but is adequately defined, for example, depending on at least one condition of a given fitting error, the amount of the shape data in analytic surface

expression form, and the corresponding amount of the polygonal shape data. This termination condition may permits the polygon of non-fitting when, in the state that the fitting error goes within the allowable

5 range and the fitting process can be terminated, the non-fitting polygon data has an advantage over the data amount. In this case, the fitting process is terminated without fitting the non-fitting polygon to the analytic surface.

10 Therefore, as shown in FIGS. 9 to 18, the first to fifth reference polygons are selected in turn to execute fitting. Respective portions of a three-dimensional object are fitted in a plane, cone, torus apple portion, torus lemon portion, and the like.

15 In FIG. 8, a polygon set generated from the reference polygon contains polygons which should belong to another surface (conic surface). The fitting destinations of such polygons are modified in step S29 in FIG. 2. FIG. 18 shows the state before step S29 in

20 FIG. 2 is executed. In this step, all the fitting results are verified again to check if each polygon is fitted in the most appropriate surface. As a result, the most appropriate fitting result is obtained, as shown in FIG. 19.

25 In cylinder/sphere identification step S30, a cylinder/sphere is identified, and the type of surface is changed in correspondence with the

identification result.

Since fitting is done for data which is not an analytic surface, the fitting result inevitably contains errors.  Such errors form gaps in a result

5   shape obtained by projecting onto fitted surfaces.

In boundary analytic curve fitting step S31, fitting is done so that the boundary between the fitted surfaces becomes a straight line or arc.  After this process, the shape expression becomes simpler, and

10  high-speed processing can be expected for the final shape data.   This process is performed by the boundary of fitted surface processing module 136.  Suchlike analytic curve is not limited only said line or arc. The analytic curve may include various kind of

15  quadratic curve.

Now, a practical use example of the fitting results in analytic surfaces by the shape expression process shown in FIG. 2 in a so-called mechanism simulation process (mechanism simulation step S32) will

20  be explained.

FIG. 21 shows an example of shapes already fitted in analytic surfaces.

In order to attain assembly in this example, relationship information indicating that there are

25  three three-dimensional shapes, i.e., components 101, 102, and 103, a plane 104 as a partial shape of the component 101 coincides with a plane 106 as a partial

shape of the component 102, and a cylindrical surface
105 is coaxial with a cylindrical surface 107 is input.

Likewise, as for the components 102 and 103,
information indicating a coincidence relationship
between planes 108 and 110, and that indicating a
coincidence relationship between planes 109 and 111 are
input to attain assembly.

All these partial shapes such as cylinders,
planes, and the like are obtained in analytic surface
fitting surface S12 mentioned above.  According to
the present invention, even when no actual data like
a cylinder is present, a cylindrical shape or the like
is automatically recognized by fitting, thus allowing
assembly modeling.

FIG. 22 expresses the storage format of relation
information associated with FIG. 21 in a storage means
such as a memory or the like of a computer in the form
of a graph.

In addition to three-dimensional shape information
and partial shape information, coincidence relation-
ships 112, 114, and 115 between planes, and a coaxial
relationship 113 between cylinders are available as
data.  A function of computing the relative positional
relationship among the components 101, 102, and 103
from these pieces of information is provided as
software in the form of a geometric constraint process
library.  3D-DCM version 2.1.0 available from D-Cubed

Ltd., United Kingdom is an example of such product. More specifically, local coordinate systems unique to components are set for individual components, and the positional relationship among components are expressed

5    in the form of a transformation matrix between these coordinate systems and a world coordinate system fixed in the space. More specifically, transformation matrices for expressing the positions of the components 101, 102, and 103 are automatically computed by the

10   geometric constraint process library on the basis of the coincidence relationships and the like shown in FIG. 22.

FIG. 23 shows an example of the positional relationship among components, which is computed to

15   satisfy all coincidence relationships defined among partial shapes, i.e., all constraint relationships among partial shapes. That is, FIG. 23 shows the positions of components obtained by applying the transformation matrices of the components automatically

20   computed by the geometric constraint process library to the shape data of the components. In this way, if analytic surfaces of cylinders, cones, spheres, and the like have been defined, kinematic pair relationships such as coincidence, coaxial, and the like among them

25   are defined, and the positions, postures, and motions among components can be computed based on these relationships.

For details of mechanism simulation, refer to US Patent Application No. 09/371843 (Japanese Patent Application No. 11-234687), "METHOD FOR CREATING ASSEMBLY MODEL" filed by the present applicant, the entire contents of which are incorporated herein by reference.

As described above, according to the first embodiment, analytic surface expression data which allows easy handling can be obtained from shape data of a three-dimensional object which is expressed by polygons like VRML. Hence, assembly modeling, mechanism simulation, and the like which can be executed by a specific CAD system alone for shape data by polyhedron approximation such as VRML or the like can be executed.

In the description of the first embodiment, a reference polygon is selected in a polygon set, and an analytic surface is fitted in a polygon set in which polygons neighbor the reference polygon and satisfy predetermined criteria (predetermined polygons make certain angles with each other). Alternatively, an equivalent polygon set may be obtained based on another process without selecting any reference polygon.

(Second Embodiment)

The second embodiment relates to a discrimination process of the presence/absence of geometric interference among three-dimensional shapes modeled

using a computer.

In polyhedron (polygon) approximation such as VRML or the like, the number of polygons tends to be huge, and when geometric interference among shapes is detected by computing them using a computer, a very long computation time is required. For this reason, it is often disadvantageous to directly use shape data obtained by polyhedron approximation in interference check.

On the other hand, when interference check is made based on analytic surfaces or the like with a small data size in place of a partial set of polyhedrons, such implementation is advantageous in terms of computation time. But when fitting results of analytic surfaces contain serious errors, interference check may produce errors due to such serious errors, and the shape data obtained by polyhedron approximation is often advantageous in terms of interference detection accuracy.

When shape data obtained by polyhedron approximation such as VRML or the like is used in interference check, although no interference takes place in practice, interference may often be erroneously detected as a result of polyhedron approximation when no interference naturally occurs like fitting of a shaft and hole as cylinders having identical diameters. In such case, the user must individually check if that

interference actually occurs or is erroneously detected as a result of polyhedron approximation. Therefore, it is important to exclude wrong interference check results caused by the internal expression of shapes, and to efficiently provide only information that the user wants.

However, no mechanism for flexibly creating appropriate shape data in accordance with the required processing time and accuracy, and applying them to the interference check function has been proposed yet, and the interference check function cannot be effectively utilized.

Hence, this embodiment provides an apparatus for flexibly checking the presence/absence of geometric interference among three-dimensional shapes in accordance with the required processing time and accuracy.

FIG. 24 is a flow chart showing a series of steps from read of shape data associated with polyhedron expression to the end of interference check according to the third embodiment of the present invention, and FIG. 25 is a block diagram showing an example of the arrangement of a program product that implements such steps on a computer.

As shown in FIG. 25, the program product comprises a shape data read module 1, analytic surface fit module 2, shape data storage/management module 3, file output

module 4, file input module 5, magnetic disk 6,
interference check data supply module 10, interference
check module 9, and result display module 11. When
shape data of analytic surface expression, which is

5     generated by the analytic surface fit module 2, need
not be permanently stored, the file output module 4,
file input module 5, and magnetic disk 6 may be
eliminated.

The interference check data supply module 10

10    comprises the shape data storage/management module 3,
a computation mode select module 7, and an interference
computation data select module 8.

In step S11 shown in FIG. 24, shape data of
polyhedron approximate expression is read. The shape

15    data read module 1 reads shape data associated with
a given mechanism component which is to undergo
interference check from, e.g., a database or the like
of a mechanism component simulation system (not shown).
The shape data of a mechanism component corresponds

20    to a three-dimensional shape, which is partially or
entirely approximately expressed by a combination of
a plurality of polyhedrons (polygons).

The shape data of polyhedron approximate
expression read by the shape data read module 1 is

25    supplied to the shape data storage/management module 3,
and also to the analytic surface fit module 2.

In step S12, an analytic surface fit process based

on the shape data of polyhedron approximate expression
read in step S11 is executed. The analytic surface fit
module 2 attempts to fit an arbitrary partial set of
polyhedrons to different analytic surfaces such as a

5      plane, spherical surface, cylindrical surface, conic
surface, torus, and the like to obtain shape data of
approximate analytic surface expression. The contents
of the analytic surface fit process are the same
as that in the above embodiment, and a detailed

10    description thereof will be omitted.

      The shape data storage/management module 3
stores and manages the shape data of analytic surface
expression generated in step S12 in association with
the corresponding shape data of polyhedron approximate

15    expression. Such shape data storage/management module
3 uses a main storage device comprising a random access
memory or the like that allows read/write at high
speed. Since the shape data of analytic surface
expression is stored and managed in association with

20    the corresponding shape data of polyhedron approximate
expression, a process for designating an analytic
surface to obtain a corresponding initial polygon set,
or the like can be made.

      It is checked in step S13 based on, e.g., a user's

25    instruction or the like if the analytic surface fit
process result in step S12 is stored not only in
the main storage device but also in a magnetic disk.

If the result is stored in the disk (step S13 = YES),
the file output module 4 writes the shape data of
analytic surface expression obtained as a result of the
analytic surface fit process in the magnetic disk 6

5 (step S14). In general, since the analytic surface fit
process requires a longer computation time than an
interference check process later, when interference
check is repeated for identical shape data, the
analytic surface fit result stored in the magnetic

10 disk 6 is read out and used in step S21 in place of
executing the analytic surface fit process in every
check, thus avoiding redundant computations and
attaining high-speed processing.

If the result is not stored in the disk in step

15 S13, the flow directly advances to step S15.

In step S15, an accuracy- or processing speed-
oriented computation mode is selected. The computation
mode select module 7 selects and determines one of
a first computation mode in which accuracy-oriented

20 interference check computations are made, and a second
computation mode in which processing speed-oriented
computations are made.

A selection criterion upon selecting such computa-
tion mode may be arbitrarily set. For example, in this

25 embodiment, when a three-dimensional shape as an object
has no motion, the accuracy-oriented first computation
mode is selected; when the three-dimensional shape

has a motion, the processing speed-oriented second

computation mode is selected.  As for the motion of the

three-dimensional shape, predetermined determination is

made based on user's operation (e.g., during animation

5    display) or the like upon simulating a mechanism

component using a model on a computer.

When the accuracy-oriented computation mode is

selected (step S16 = YES), the interference computation

data select module 8 issues a data request to the shape

10   data storage/management module 3 to select shape data

(polygon) of polyhedron approximate expression of

a portion other than those in which analytic surfaces

are fitted without any errors.  That is, the shape

data of polyhedron approximate expression is used in

15   interference check in place of the already obtained

analytic surface expression, so as to prevent any

errors due to the fit process (step S17).

FIG. 25 shows an example of polyhedron data of

a three-dimensional shape provided by, e.g., VRML.

20   In this polyhedron data, analytic surfaces (plane,

cylindrical surface, conic surface, spherical surface,

and the like) are accurately fitted (without any

errors) as a result of the analytic surface fit process

(step S12), as shown in FIG. 26.  In this case, it is

25   advantageous to conduct interference check using

the fitted analytic surfaces in terms of both the

processing speed and accuracy.  Therefore, when

analytic surfaces are accurately fitted, i.e., when no errors are produced upon fitting analytic surfaces, the subsequent processes (interference check) are executed using the fitted analytic surfaces independently of the

5  computation mode selected.

Polyhedron data shown in FIG. 27 is data that pertains to a three-dimensional shape which is slightly different from that in FIG. 19, and is used to explain a case wherein the analytic surface fit process causes

10  errors.  In FIG. 27, a portion 110 is a slowly tapered portion, which is different from an approximate shape shown in FIG. 19.  For example, the presence of this tapered portion often causes an error (analytic surface 111) in the analytic surface fit result.

15  An analytic surface fit error can be detected by a distance computation between a point on that analytic surface and a reference point (e.g., a point on a polyhedron corresponding to this point).  The interference computation data select module 8 specifies

20  the analytic surface 111 containing an error, and selects initial shape data of polyhedron approximation corresponding to this analytic surface 111.

Note that the analytic surface fit result may be displayed on the display screen, and the user

25  may visually detect any fit errors.  When the user explicitly designates the analytic surface 111 where an error has been produced, the interference computation

data select module 8 selects initial shape data of polyhedron approximation corresponding to the designated analytic surface 111.

On the other hand, if the processing speed-oriented computation mode is selected (step S16 = NO) in FIG. 24, a largest possible number of analytic surfaces are selected. The interference check process can be executed at higher speed if an increased number of portions have analytic surfaces selected. For example, in this embodiment, analytic surfaces are selected independently of the presence/absence of the aforementioned fit errors.

The shape data selected in step S17 or S18 are supplied to the interference check module 9. The interference check module 9 executes the interference check process on the basis of the supplied shape data (step S19). For example, CDM (Collision Detection Manager) available from D-Cubed Ltd., United Kingdom is known as a software library effective for implementing the interference check process, and interference detection among analytic surfaces can be detected at very high speed using that software library. Note that application of that software library is merely an example. The interference check result in step S19 is displayed on the result display module 11.

It is checked in step S15 if the interference check process is to end. If interference check is

redone under different conditions in accordance with
user's instruction or the like, the flow returns to
step S15. At this time, the analytic surface fit
result recorded in the magnetic disk 6 can be used,

5      as described above. Without using the recorded result,
a new analytic surface fit process under different
conditions may be done.

Some modifications of this embodiment will be
described below.

10      In this embodiment, in the accuracy-oriented
computation mode, shape data of polyhedron approximate
expression is selected for an analytic surface
containing a fit error in place of the corresponding
shape data of analytic surface expression, thus

15      generating appropriate shape data corresponding to
the processing method. However, analytic surface
expression may be more advantageous than polyhedron
approximate expression in terms of interference check
accuracy in some cases.

20      FIGS. 9A and 9B are views for explaining such
case. FIGS. 9A and 9B show the fitting state
(shaft-hole pair) of a shaft (cylindrical surface) and
hole when viewed from the axial direction of the hole.
In practice, the hole diameter nearly matches the shaft

25      diameter, but the shaft is slightly smaller than the
hole for the sake of simplicity.

As shown in FIG. 29A, when cylindrical surfaces as

analytic surfaces are fitted in a shaft 151 and hole 152, no interference takes place when the shaft 151 and hole 152 rotate relative to each other (e.g., the shaft rotates relative to the immovable hole). By contrast, when no analytic surfaces are fitted in a shaft 153 and hole 154, which remain expressed by polyhedrons, if the shaft 153 and hole 154 rotate relative to each other, interference takes place depending on the rotational angle. Reference numerals 155 and 156 denote interference portions in this case. FIG. 29B shows an example wherein interference that never occurs in practice is erroneously detected due to polyhedron expression, and which is often found upon modeling and simulation of mechanism components. In such case, the shape data of analytic surface expression may be exclusively used independently of the computation mode.

As another modification, a plurality of analytic surface fit results or shape data of polyhedron approximate expression may be prepared on the basis of an allowable error value. In approximation of these three-dimensional shapes, if larger errors are set, the number of approximate surfaces decreases, and high-speed processing is guaranteed, but precision impairs. On the other hand, when smaller errors are set, the number of approximate surfaces increases, and accuracy can be improved, but the processing time is prolonged. In this embodiment, two different choices of shape

data, i.e., analytic surface expression and polyhedron
approximate expression, are available, but more choices
may be provided.  For example, accurate data, data with
small errors, and data with large errors are prepared.

5      These data are selectively used in accordance with the
motion speed or the like in animation of a component to
be checked.  For example, when a three-dimensional
object moves at high speed, data with large errors may
be used to attain high-speed interference check, and

10     when the motion of the object becomes slow, data with
small errors may be selected.  When the motion stops
finally, accurate data may be used.

       . As still another modification, a three-dimensional
shape may be redundantly and approximately expressed

15     using analytic surfaces, thus improving accuracy and
reliability of interference check.

       When very strict accuracy is required upon
detecting the presence/absence of interference among
components, since analytic curve expression shown in

20     FIG. 28 contains fit errors, as described above,
troubles or oversight may occur in interference check.
Hence, a three-dimensional shape is redundantly and
approximately expressed.  More specifically, as shown
in FIG. 30, original polygons are expressed by

25     sandwiching them between an analytic surface 111 formed
by a partial shape of an approximate conic surface,
and another surface which has a common central axis

to the analytic surface 111 and a smaller radius.
If interference occurs on any surface, the presence
of interference is determined. In this case, two
approximate surfaces are inevitably used to sandwich
polygons, and it is disadvantage for the interference
check process in terms of time. However, the
interference check process can be executed at
sufficiently higher speed than a case using only shape
data of polyhedron approximate expression. Even when
an obstacle approaches a polygon set from any
direction, as it collides against one of the two
approximate surfaces, possibility of troubles and
oversight in interference check can be excluded.

FIG. 31 explains such principle of obtaining two
surfaces in more detail to attain reliable interference
check. In FIG. 31, the central axes of a fitted cone
and cylindrical surface are indicated by the one-dashed
lines, and the full circles indicate a state wherein
the vertices of fitted polygons rotate about these
central axes and are projected onto planes including
the axes. The dotted lines indicate the fitted cone
and cylindrical surface, but the dots indicated by the
full circles are not always strictly located on the fit
surfaces and slight interference may fail to be found.
Hence, in a cone, two surfaces indicated by the solid
lines are obtained by vertically moving the fitted
cylinder along the axis to spuriously increase/decrease

the radius at an original position.  In case of a
cylinder, a pair of cylinders indicated by the solid
lines can be obtained by directly increasing/decreasing
its radius.

5        As described above, according to the second
embodiment, shape data of analytic surface expression
that can be processed at high speed is effectively
used, and when accurate computations are required,
initial shape data of polyhedron approximate expression

10       is used in addition to accurately fitted analytic
surfaces, thus implementing flexible interference check
in accordance with the required processing time and
accuracy.

         Additional advantages and modifications will

15       readily occur to those skilled in the art.  Therefore,
the invention in its broader aspects is not limited to
the specific details and representative embodiments
shown and described herein.  Accordingly, various
modifications may be made without departing from the

20       spirit or scope of the general inventive concept as
defined by the appended claims and their equivalents.